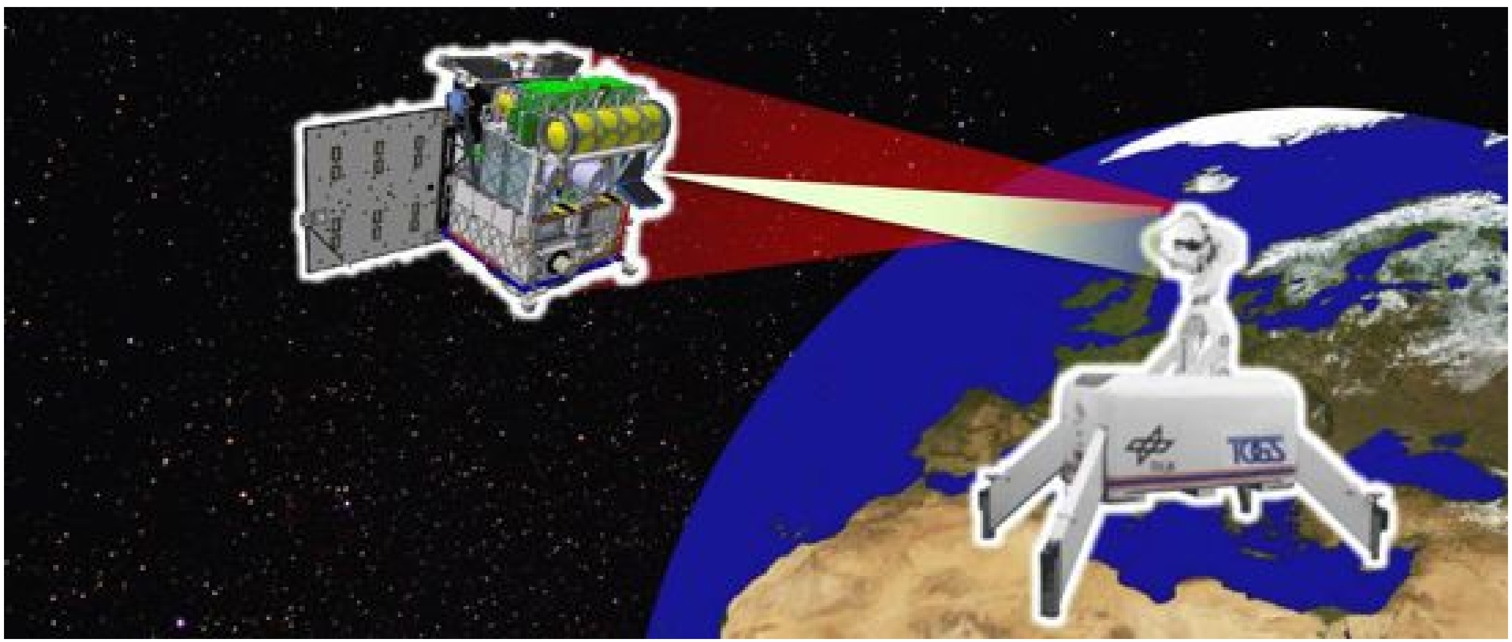
Workshop on Optical LEO Downlinks

Institute of Communications an Navigation
German Aerospace Center

10th November 2016



The Transmission Scenario in Optical LEO Downlinks

OLEODL-Workshop, DLR-IKN, 10th November 2016

Dirk Giggenbach

DLR

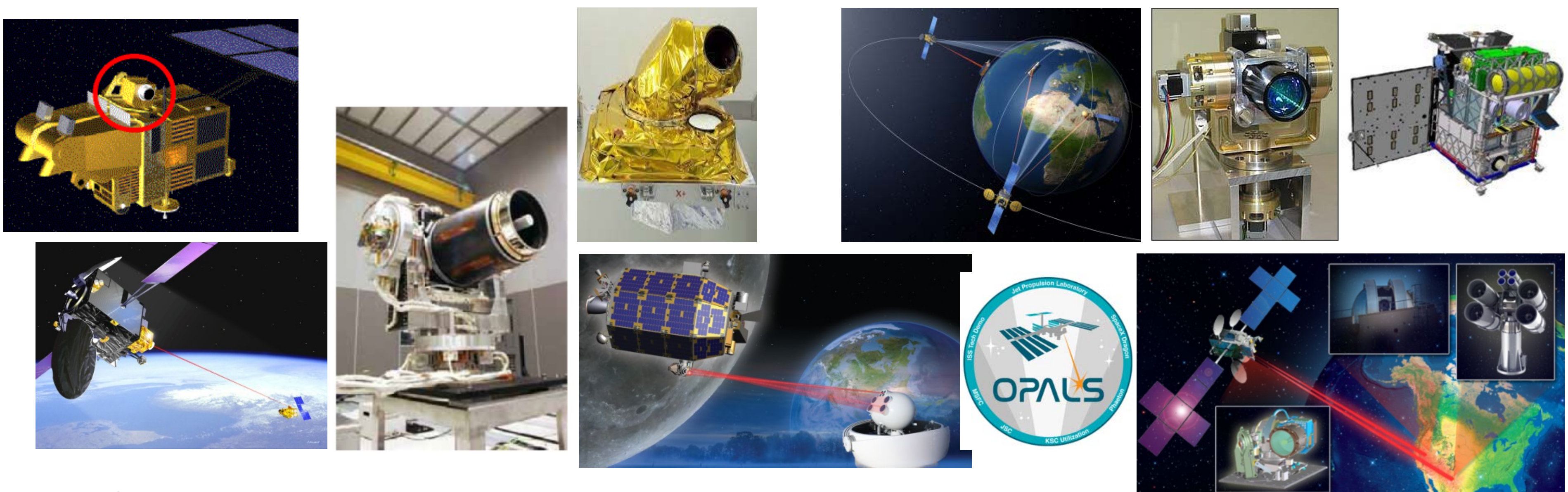
Content

- Example of an OLEODL experiment: KIODO
- Link Geometry
- Atmospheric Attenuation
- Fading in Downlink
- Gain by Aperture Averaging
- Link Budget

Timeline of Laser-Comm. Space-Missions (selection)

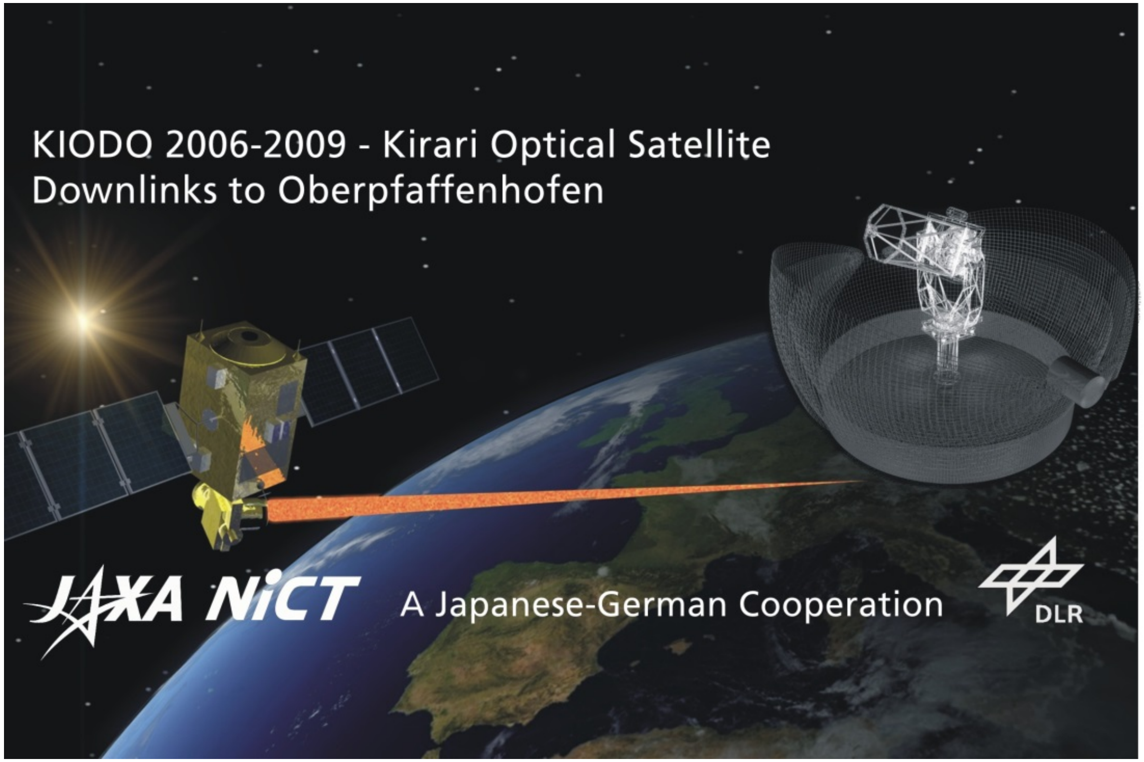
…*with DTE-Links*

1994	1998	2001	2005	2007	2013	2014	2016	2017	2018
•ETS-VI	•SPOT-4	•Artemis → SILEX •GEOLITE	•OICETS	•LCTSX •NFIRE	•α-Sat •LLCD	•Sentinel-1A •SOTA •OPALS	•EDRS-A •OSIRIS-2	•EDRS-C •OSIRIS-1	•LCRD



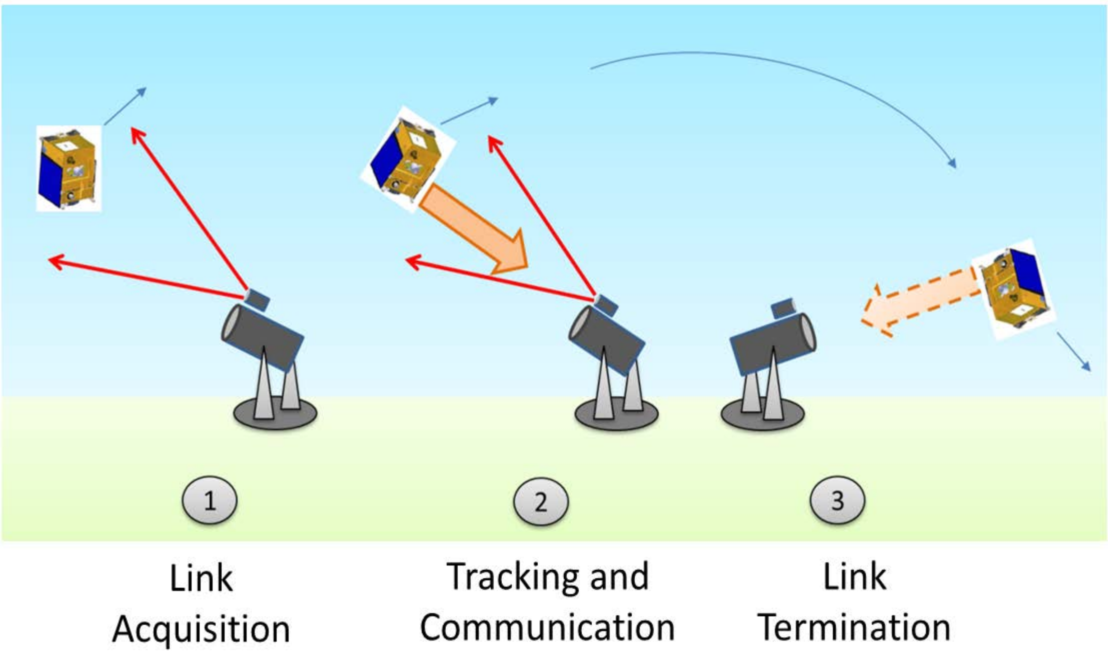
Pictures: ESA, JAXA, NICT, NASA, MIT, DLR

KIODO: Kirari Optical Downlinks to Oberpfaffenhofen



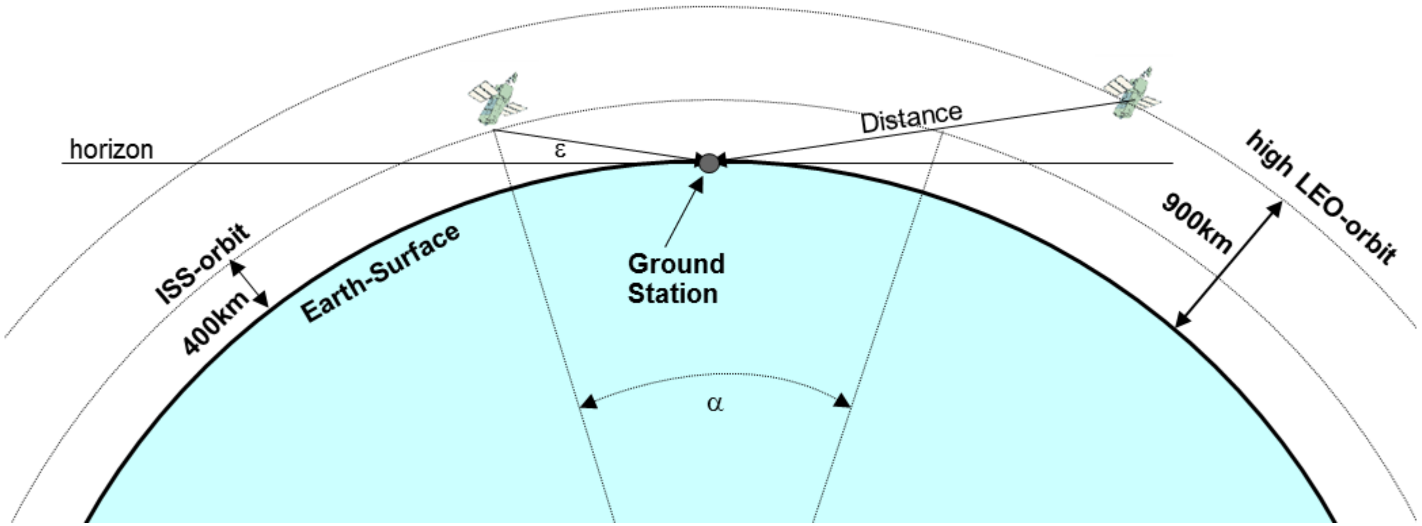
- Cooperation between DLR and JAXA/NICT
- Measurement Campaigns in 2006 & 2009
- Channel Characterization:
    - Intensity Scintillation and Wavefront-Distortions
    - Communication Performance by the Bit Error Ratio

Phases of a OLEO Down-Link



- Knowledge of Orbit allows open-loop pointing of OGS‘s Beacon
- Satellite Terminal‘s extended FoV detects beacon
- Reorientation/Pointing of Downlink Signal from Satellite
- Data signal also allows precise tracking at OGS
- Link is terminated at low elevation

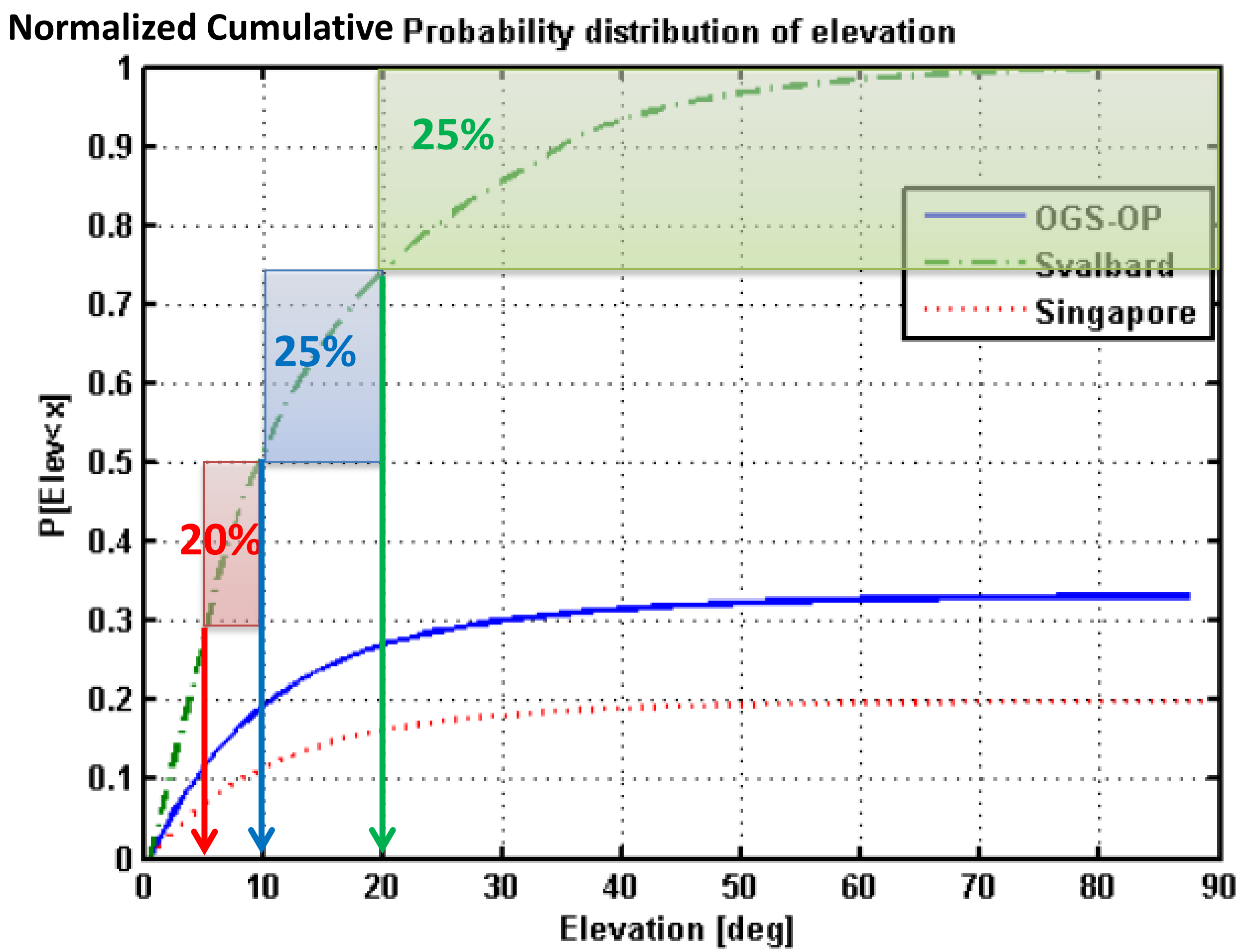
Typical LEO-DTE Link Geometry
Low and High LEO orbit



Orbit:	Distance at 5°	max. link duration 5°	Sat-Velocity	slew-rate at zenith	point-ahead (polar orbit)
400km circular	1804 km	475 s	7.67 km/s	1.1 °/s	51 µrad
900km circular	2992 km	831 s	7.40 km/s	0.48 °/s	49 µrad

DTE: Direct-to-Earth

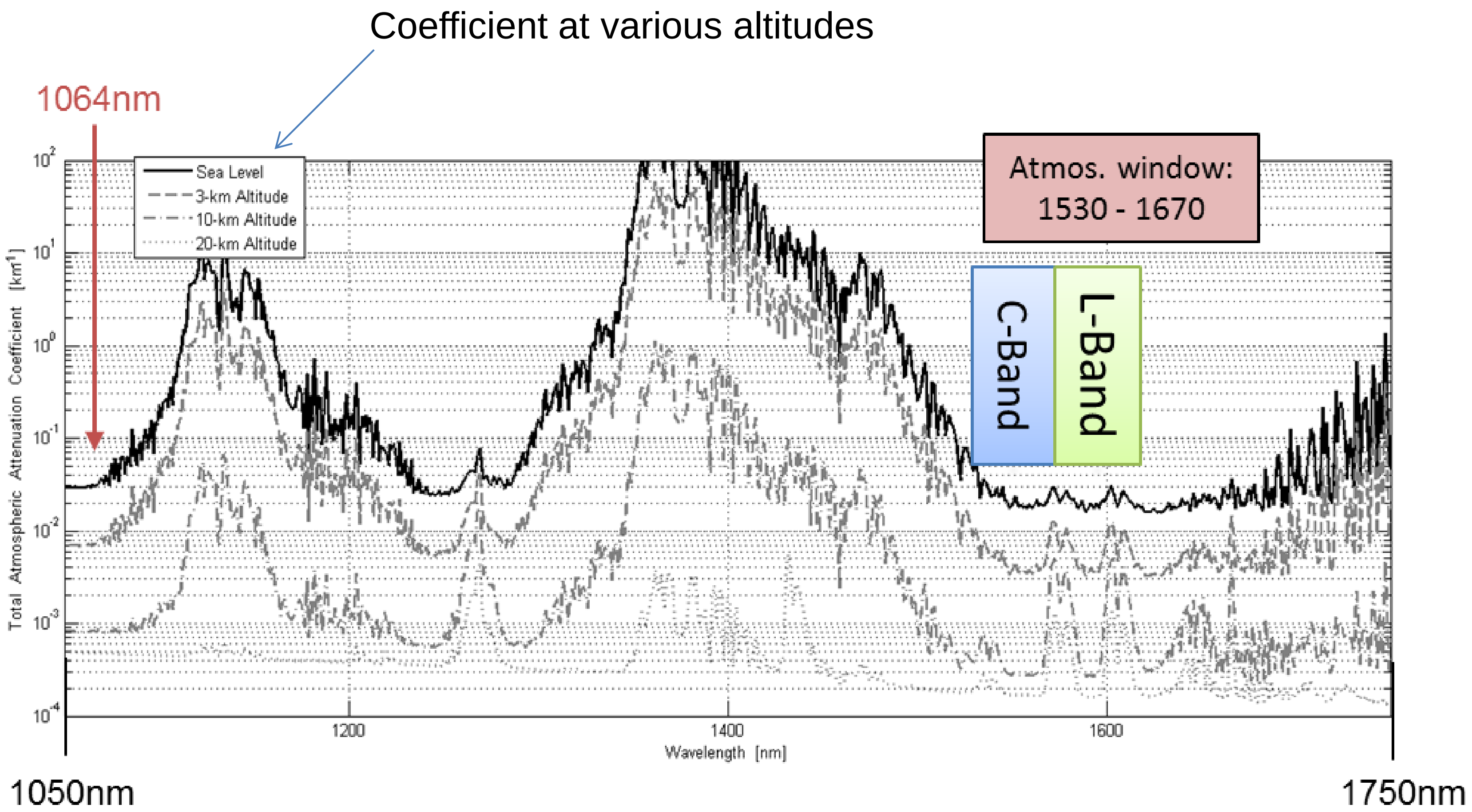
Typical LEO-DTE Elevation Distribution



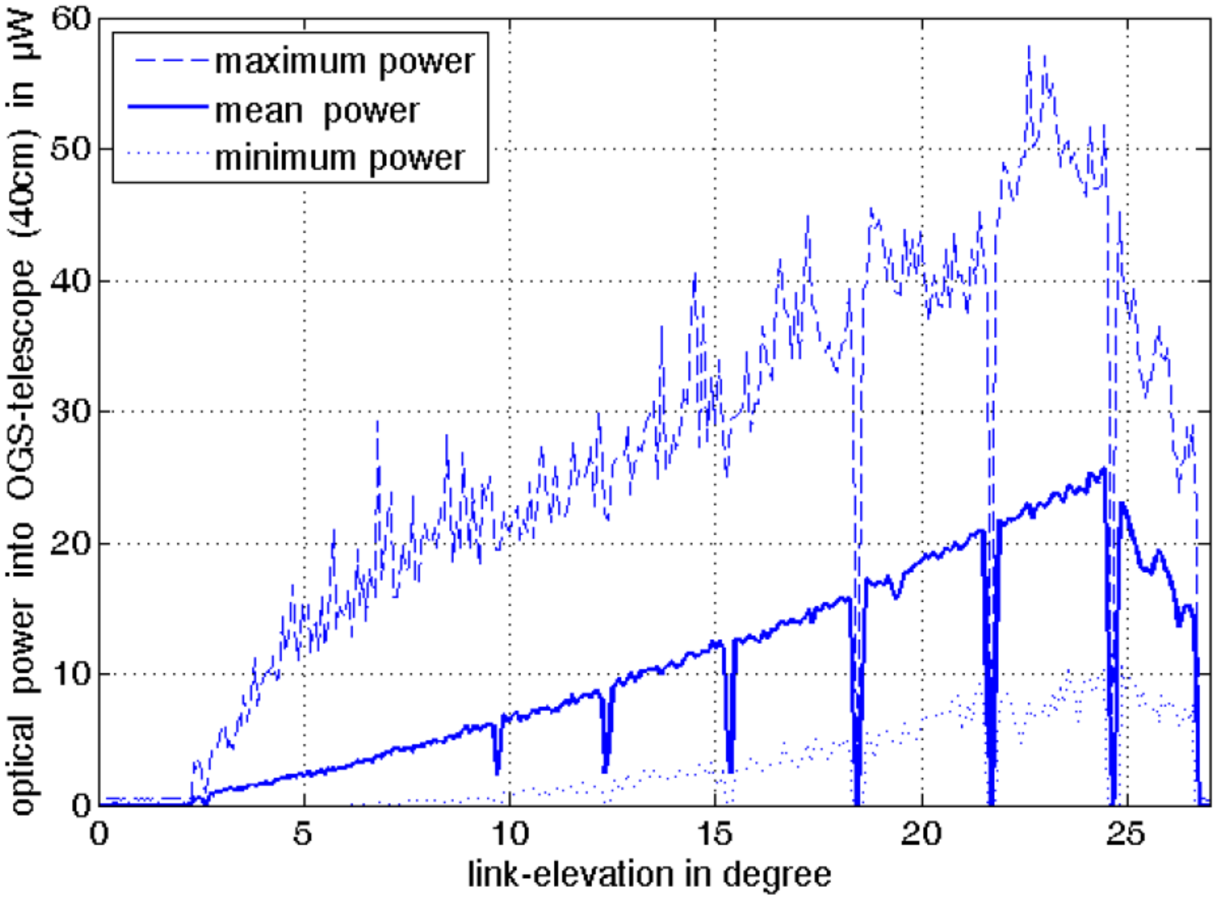
500km orbit

Giggenbach, Moll, Fuchs, de Cola, Mata-Calvo, "SPACE COMMUNICATIONS PROTOCOLS FOR FUTURE OPTICAL SATELLITE-DOWNLINKS", IAC 2011

Atmospheric Transmission Coefficient: Detail NIR



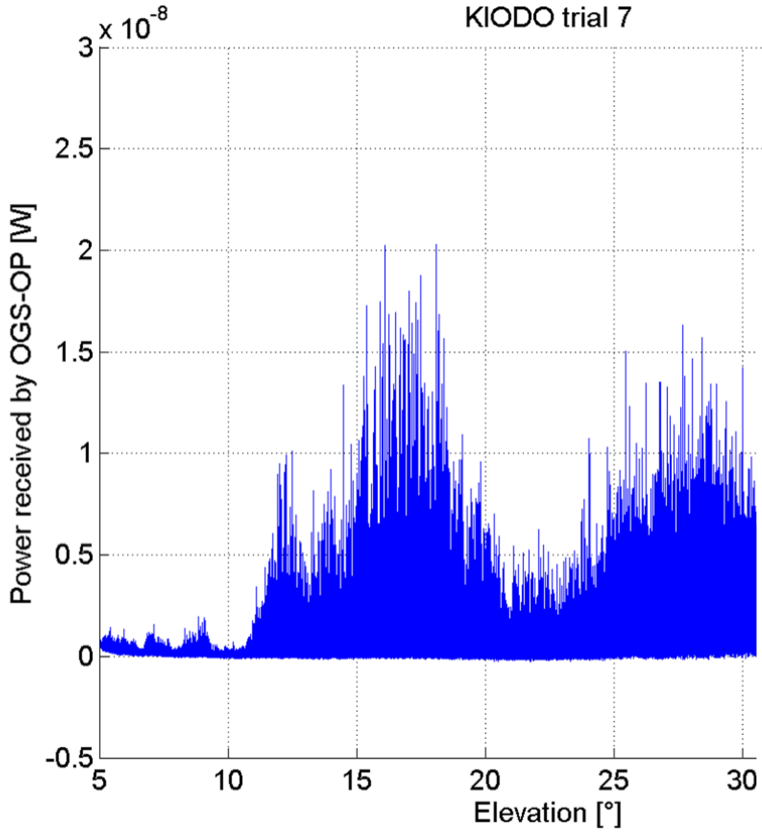
Scintillating Signal over Elevation



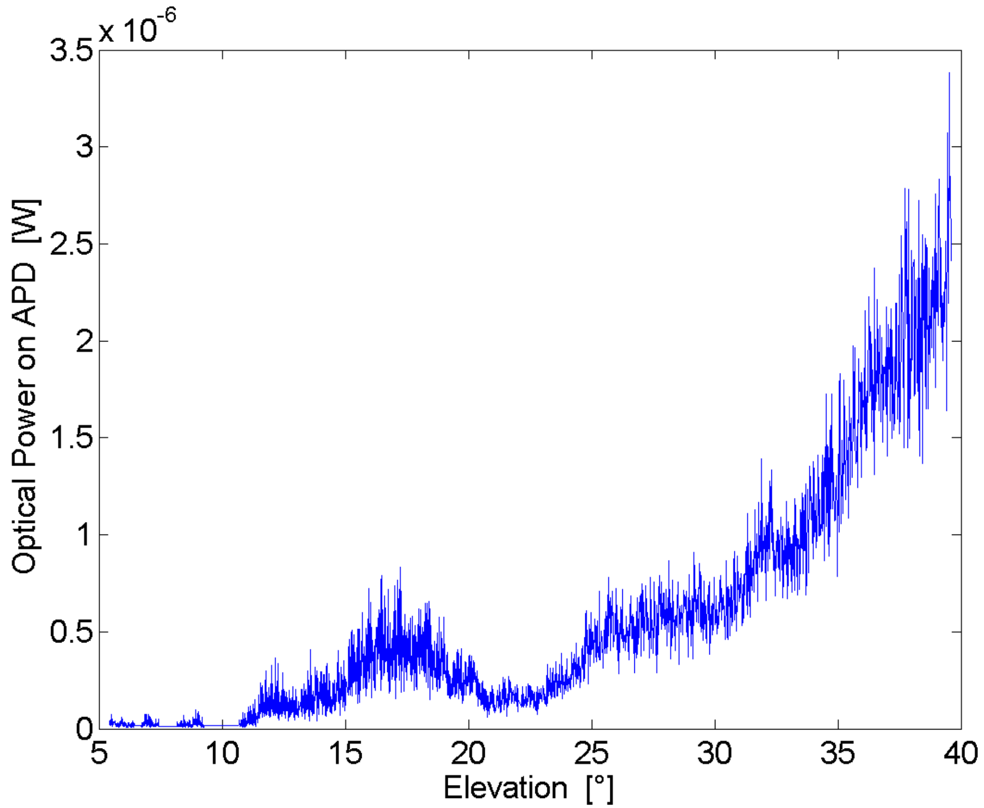
into 40cm OGS-aperture
KIODO-2006, 847nm

Aperture Averaging in OLEODL: 2 Aperture sizes

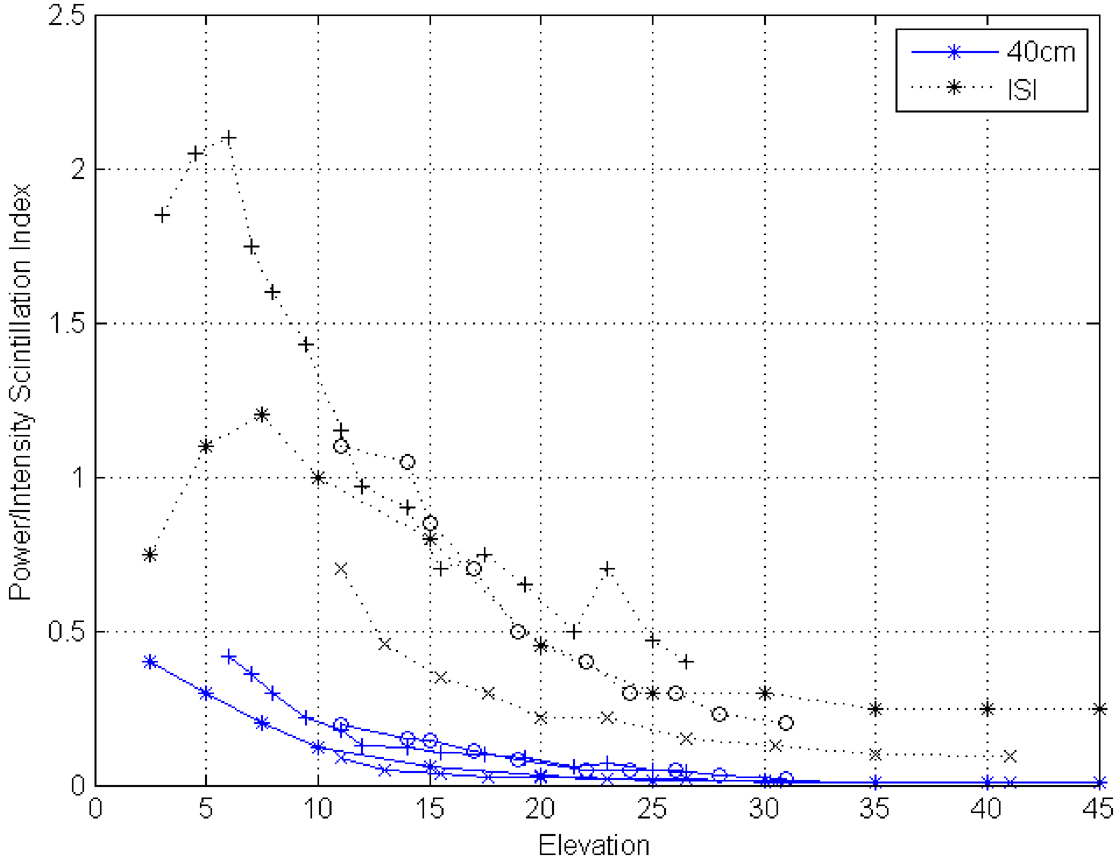
power into 5cm:



…same pass: power into 40cm



Aperture-Averaging:
ISI and PSI from several OLEODLs



KIODO, 847nm

ISI: Intensity Scintillation Index
PSI: Power Scintillation Index

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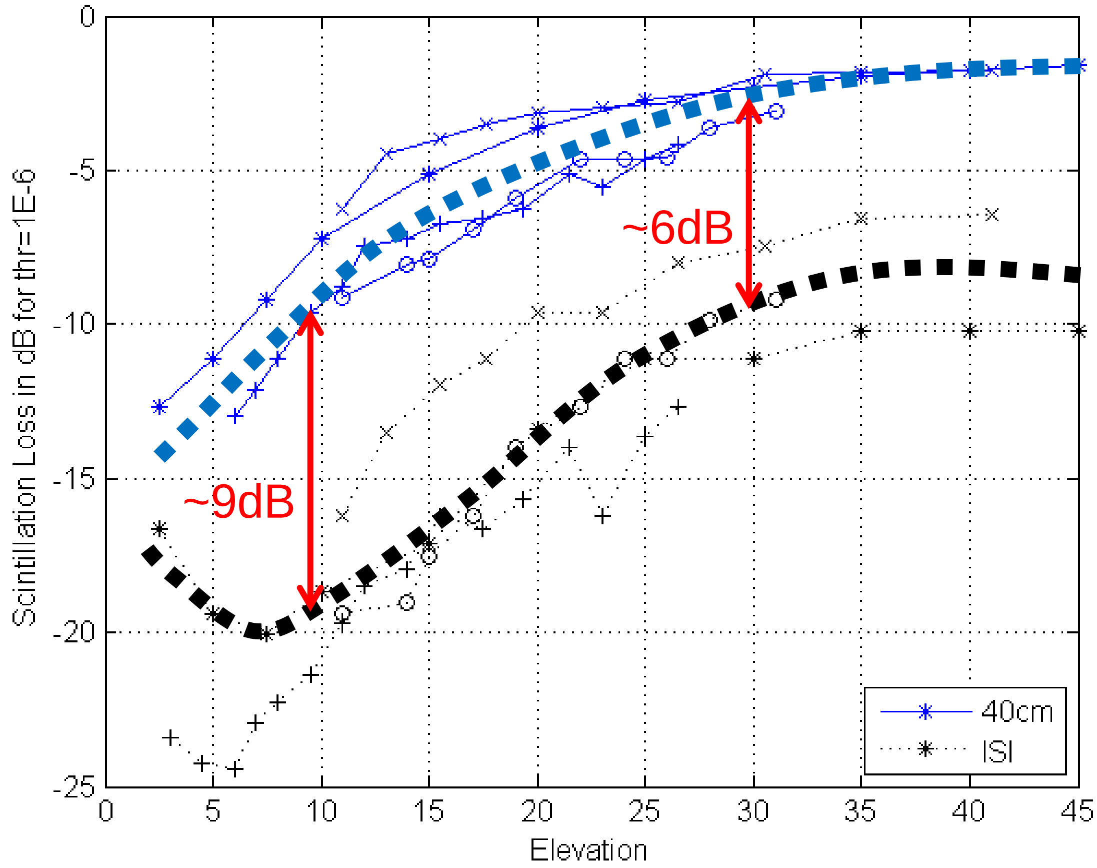
Aperture Averaging: Scintillation-“Gain“

…with lognormal fading: $a_{\text{scint}} = f\left(\sigma_I^{\;2}, D_{aperture}\right)$



Example: 847nm

Typical Link Budgets for 400km and 900km orbit height

	Parameter	unit	400 km Orbit 5°	10°	15°	20°	900 km Orbit 5°	10°	15°	20°
Tx	mean modulated signal pow er	W	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	optical Tx loss	dB	-1.49	-1.49	-1.49	-1.49	-1.49	-1.49	-1.49	-1.49
	Tx-divergence FWHM	mrad	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	Tx-divergence 1/e² (full angle)	mrad	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
	Tx-telescope gain	dB	98.19	98.19	98.19	98.19	98.19	98.19	98.19	98.19
	Pointing Penalty	dB	-3.01	-3.01	-3.01	-3.01	-3.01	-3.01	-3.01	-3.01
Comm. System	data rate	Gbps	2.50	10.00	10.00	10.00	1.00	5.00	10.00	10.00
	Wavelength	nm	1550.00	1550.00	1550.00	1550.00	1550.00	1550.00	1550.00	1550.00
	Modulation Format	-	IM/DD	IM/DD	IM/DD	IM/DD	IM/DD	IM/DD	IM/DD	IM/DD
	Bit Error Rate	-	1.0E-06	1.0E-06	1.0E-06	1.0E-06	1.0E-06	1.0E-06	1.0E-06	1.0E-06
	Receiver Sensitivity @ BER	Ph/Bit	800.00	800.00	800.00	800.00	800.00	800.00	800.00	800.00
Channel	link distance	km	1804.00	1439.00	1175.00	984.00	2992.00	2568.00	2224.00	1947.00
	Free-space loss	dB	-263.30	-261.34	-259.58	-258.04	-267.70	-266.37	-265.12	-263.96
	Scintillation Loss	dB	-5.00	-3.50	-2.50	-1.70	-5.00	-3.50	-2.50	-1.70
	Atmospheric attenuation	dB	-8.00	-4.00	-3.00	-2.00	-8.00	-4.00	-3.00	-2.00
Rx	Aperture Diameter	cm	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
	Rx telescope gain (ideal)	dB	121.70	121.70	121.70	121.70	121.70	121.70	121.70	121.70
	Loss due to secondary mirror	dB	-0.28	-0.28	-0.28	-0.28	-0.28	-0.28	-0.28	-0.28
	Optical Rx Losses	dB	-6.02	-6.02	-6.02	-6.02	-6.02	-6.02	-6.02	-6.02
	Rx-Pow er after Losses	dBm	-37.21	-29.75	-25.98	-22.64	-41.60	-34.78	-31.53	-28.57
Comms	Splitting Ratio to Comm Sensor	dB	-0.46	-0.46	-0.46	-0.46	-0.46	-0.46	-0.46	-0.46
	Tracking/Coupling Loss	dB	-0.97	-0.97	-0.97	-0.97	-0.97	-0.97	-0.97	-0.97
	Rx-pow er onto comm-detector	dBm	-38.64	-31.17	-27.41	-24.07	-43.03	-36.20	-32.95	-30.00
	Coding Gain	dB	3.98	3.98	3.98	3.98	3.98	3.98	3.98	3.98
	Eff. rx pow er on comm-detector (incl. Coding)		-34.66	-27.19	-23.43	-20.09	-39.05	-32.22	-28.97	-26.02
	Required Pow er (Rx-sensitivity)	dBm	-35.91	-29.89	-29.89	-29.89	-39.89	-32.90	-29.89	-29.89
	Communication Margin	**dB**	**1.3**	**2.7**	**6.5**	**9.8**	**0.8**	**0.7**	**0.9**	**3.9**

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Summary

- One single OLEODL pass shows extreme static variation over elevation → ~15dB
- Additional dynamic variation due to IRT (scintillation) → ~10dB
- Aperture Averaging with multimode receivers allows mitigation of IRT → ~8dB
- 10 Gbps are practical above 15° elevation
- ***10 Years of Experiments and Demonstrations paved the way towards operational use***

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